An Overview of Hilbert-Huang Transform-based Earthquake Source Characterization using Strong Motion Data

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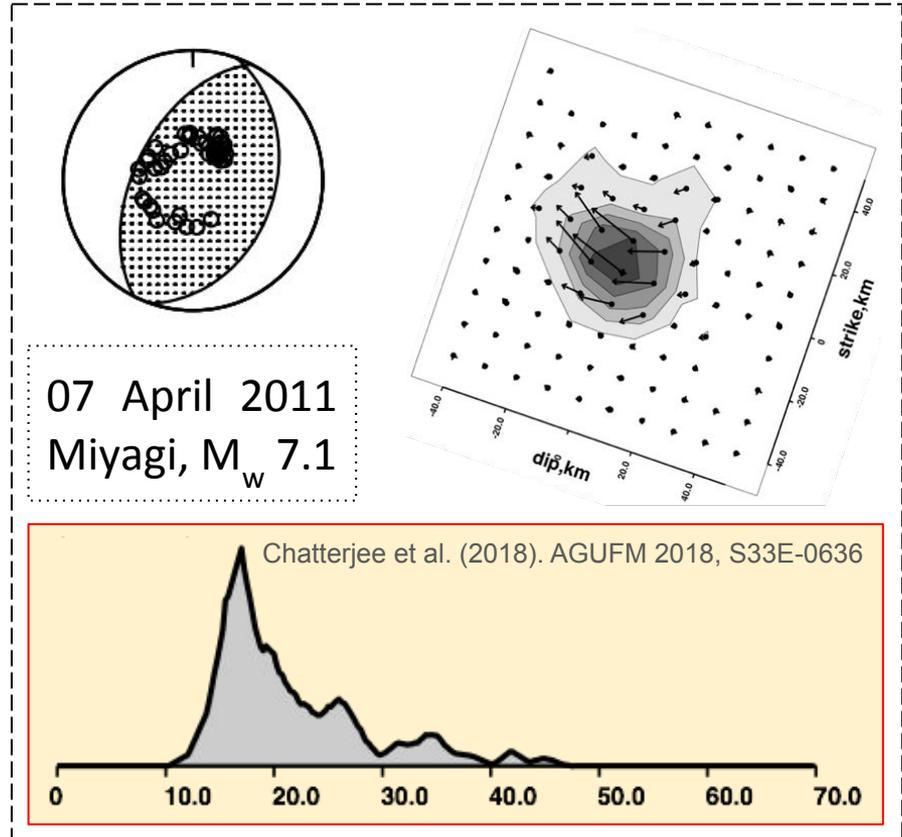
07 April 2011
Miyagi, M_w 7.1

Chatterjee et al. (2018). AGUFM 2018, S33E-0636

Harnessing **time-frequency analysis tools** + empirical mode decomposition to represent energy release


11 March 2011
Tohoku, M_w 9.0

Time-Frequency Representations
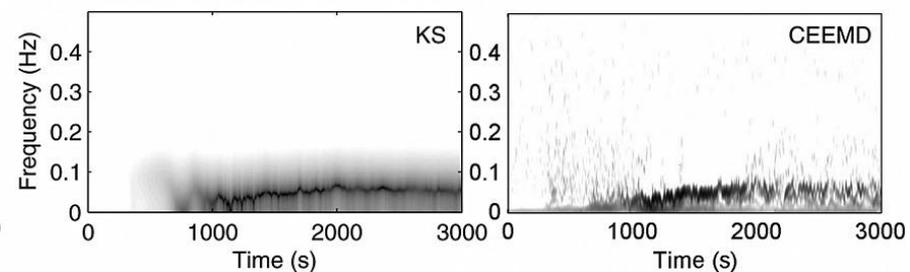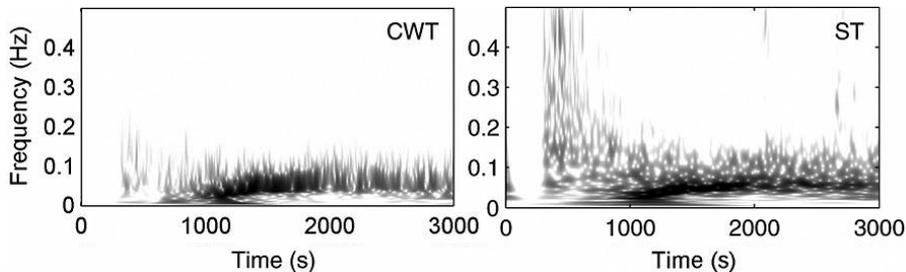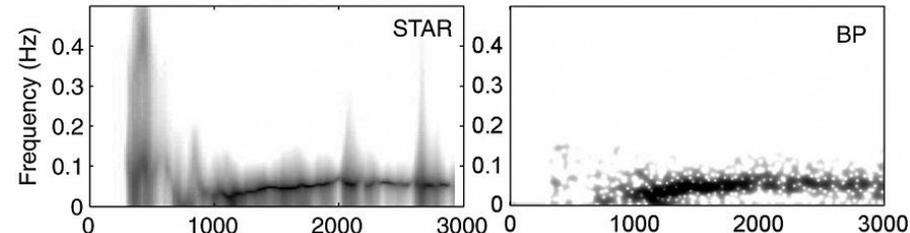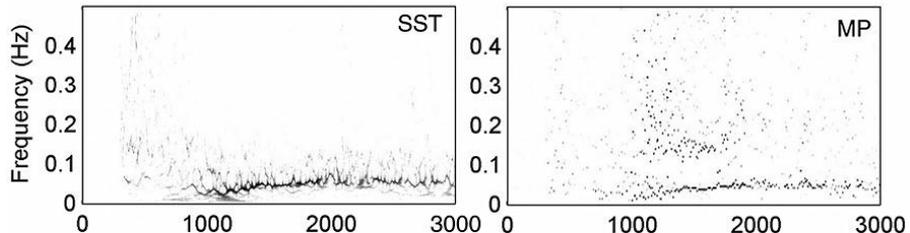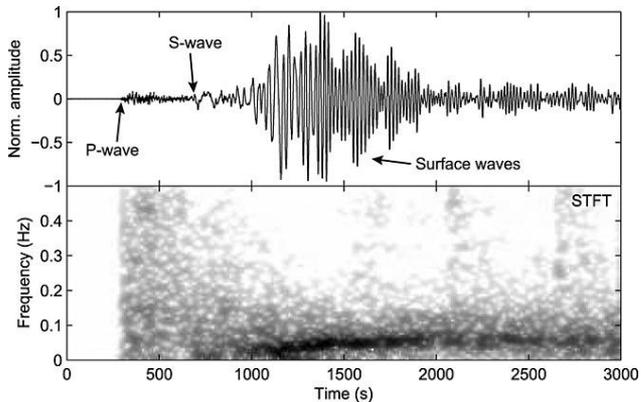
Tary et al. (2014). *Rev. Geophys.*, 52, 723-749

Harnessing time-frequency analysis tools + **empirical mode decomposition** to represent energy release
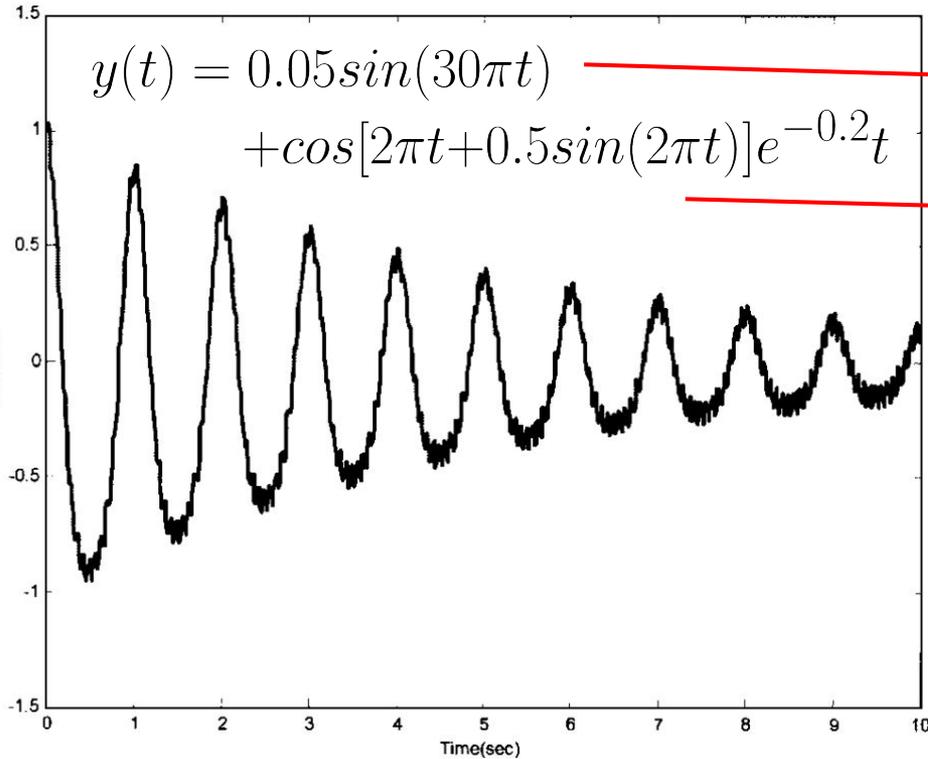
$$y(t) = 0.05 sin(30\pi t)$$
$$+ cos[2\pi t + 0.5 sin(2\pi t)]e^{-0.2t}$$

Intrinsic Mode Functions

Signal y(t)

Zhang, Ma, and Hartzell (2003). BSSA, 93 (1): 501–518

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# Heterogeneous energy-release and frequency content depending on tectonic setting and depth

Ye, Lay, and Kanamori (2013). BSSA, 103, 1221-1241

4
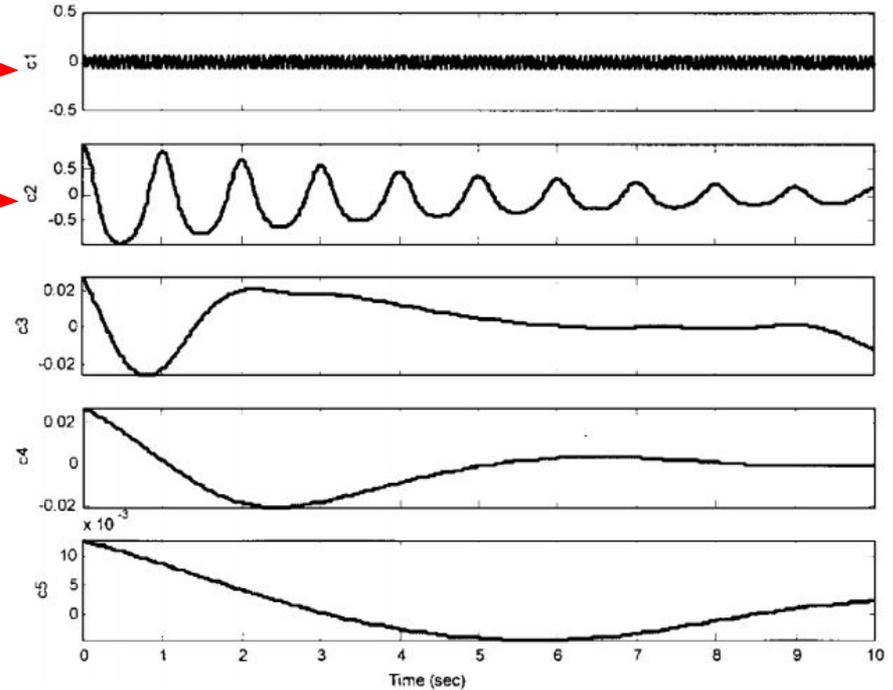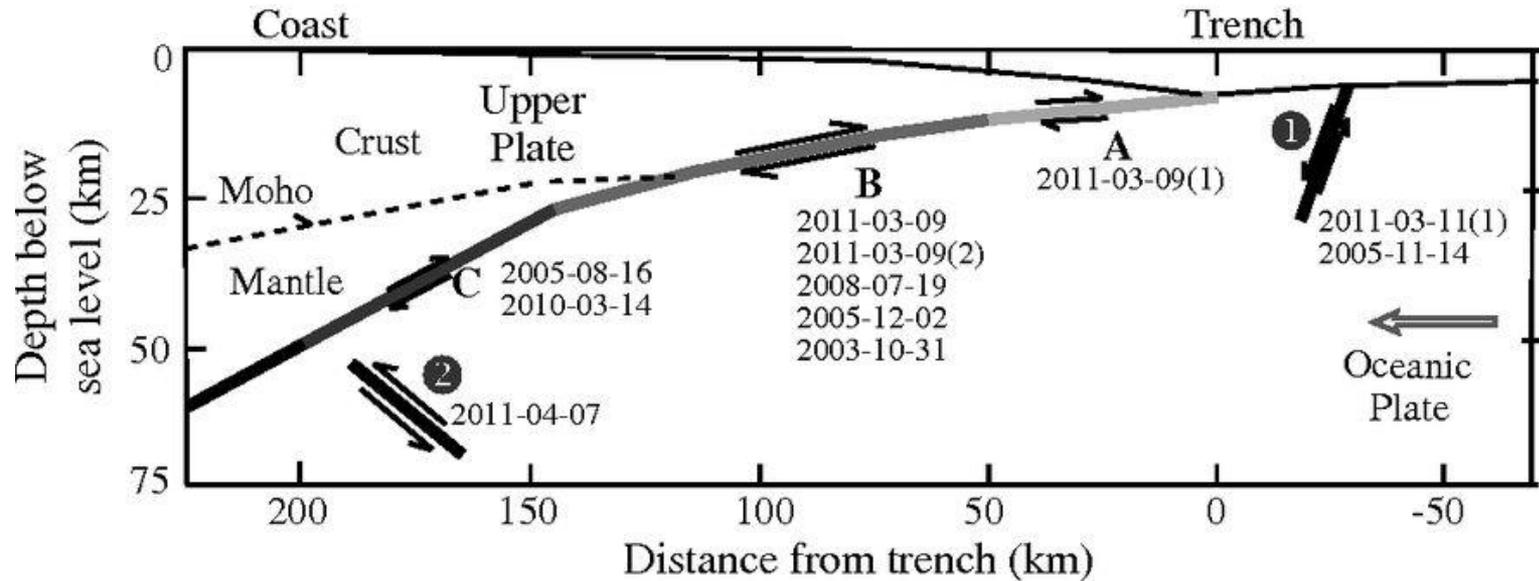
Heterogeneous energy-release and frequency content depending on tectonic setting and depth

Intraplate

Heterogeneous energy-release and frequency content depending on tectonic setting and depth

4

Heterogeneous energy-release and frequency content depending on tectonic setting and depth

4
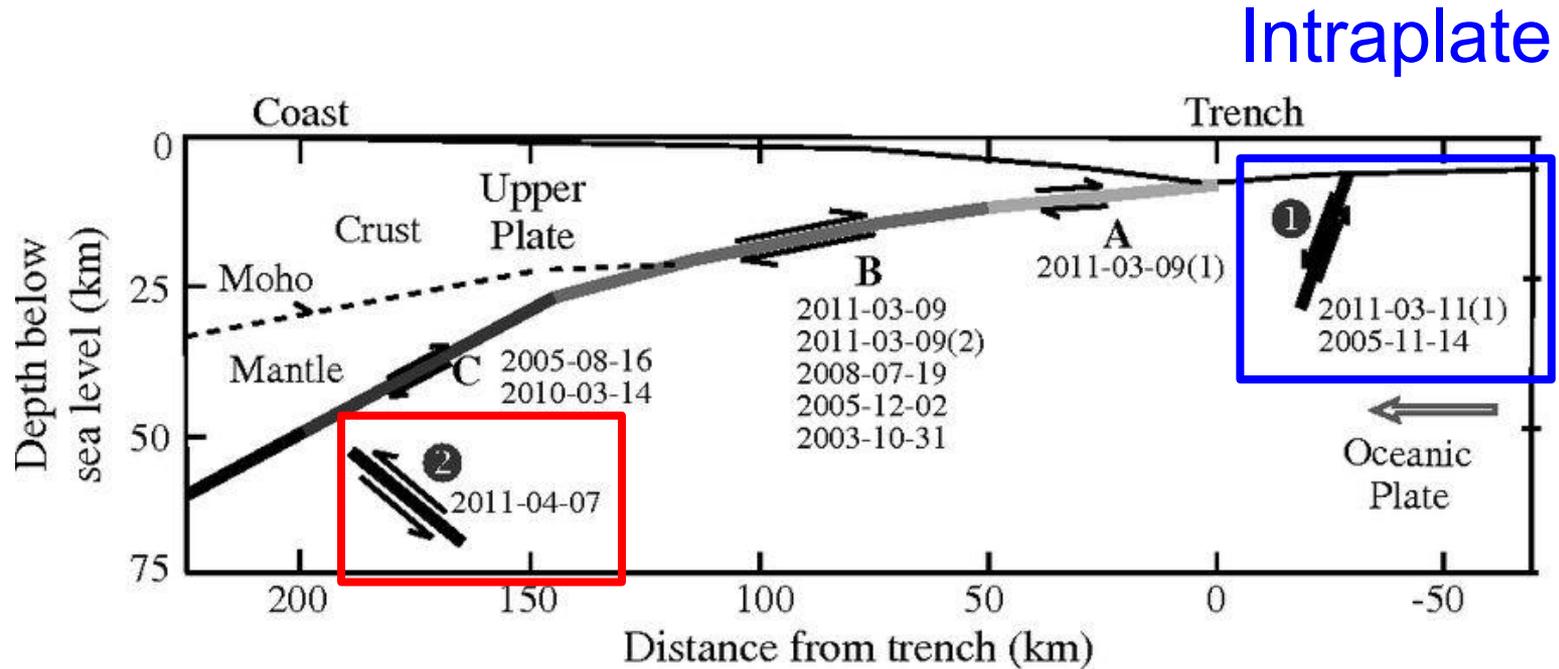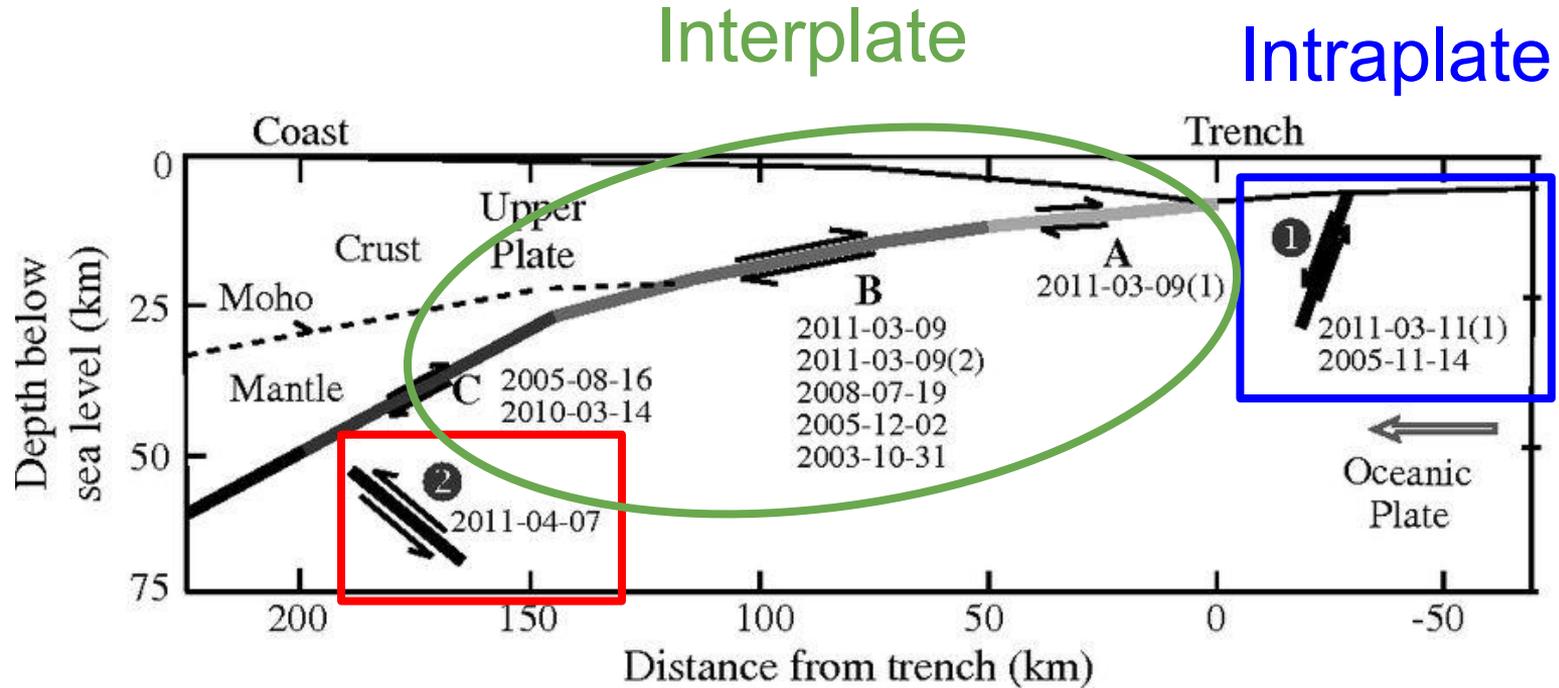
# Spectral amplitudes: Interplate < Intraplate < Intraslab

5

# Interplate: increasing high-frequency energy and energy/moment with depth

Ye, Lay, and Kanamori (2013). BSSA, 103, 1221-1241

6

Interplate: increasing high-frequency energy and energy/moment with depth
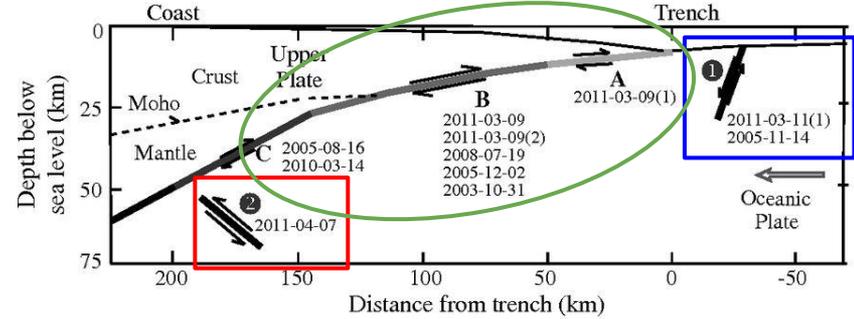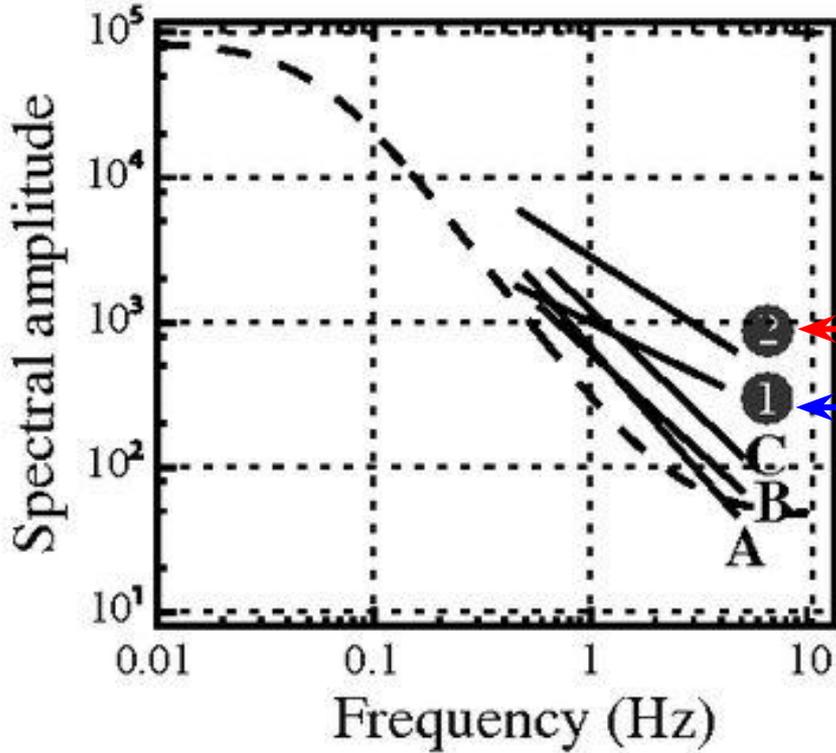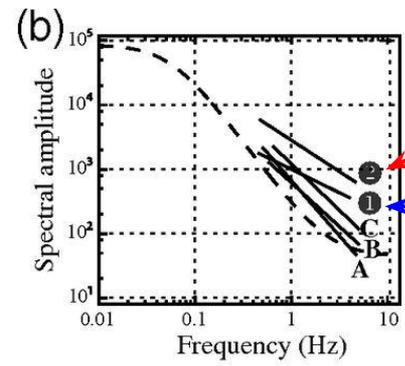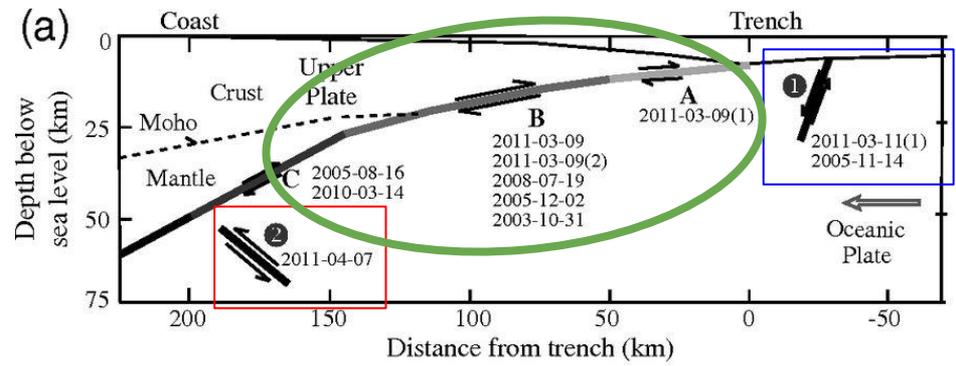

Intraslab

Intraplate

Interplate
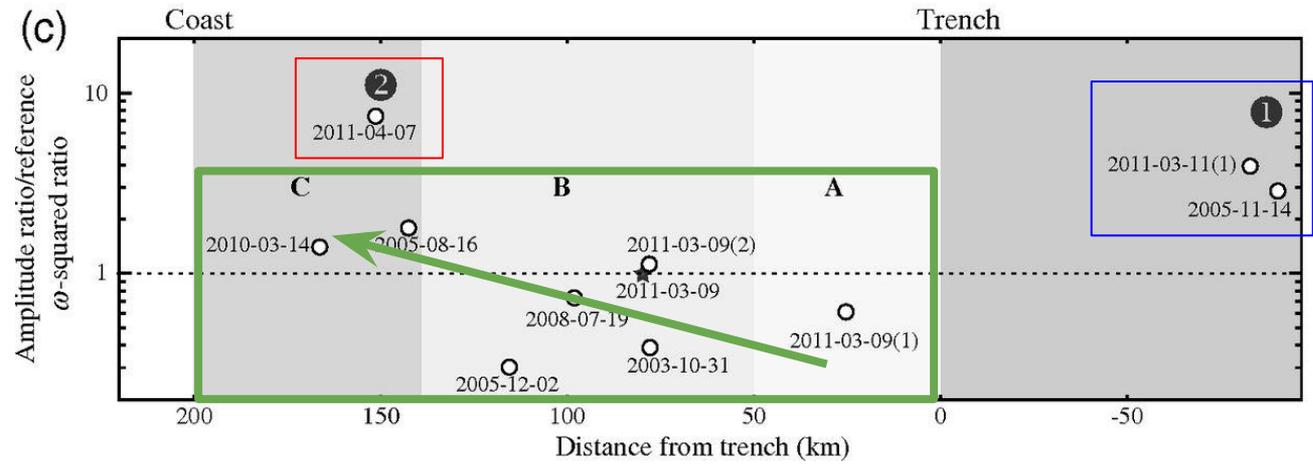
6

Time-frequency analysis of intrinsic mode functions decomposed from earthquake strong-motion data
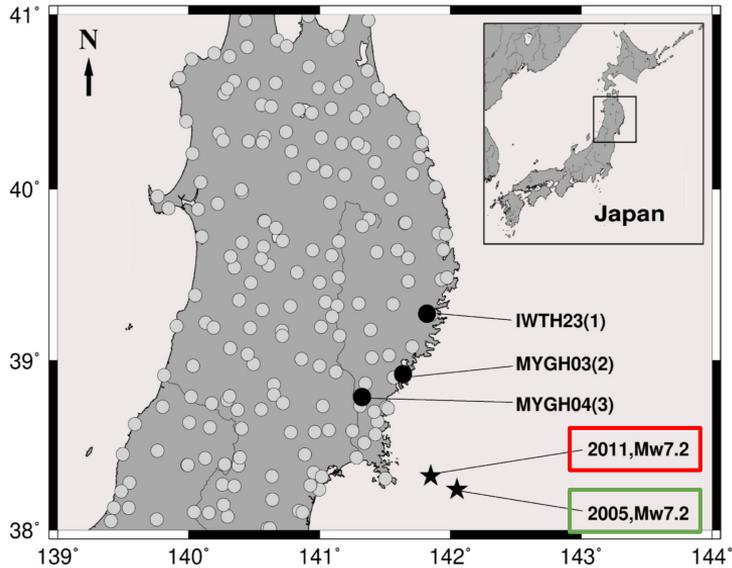

Intraslab

Interplate
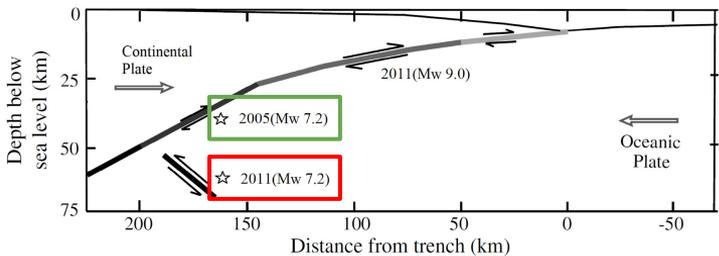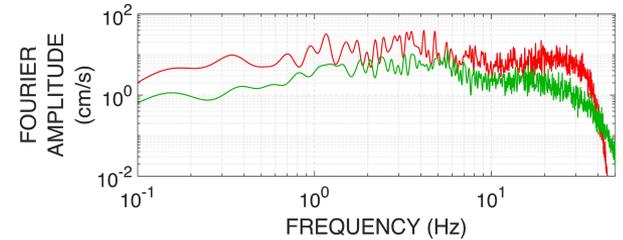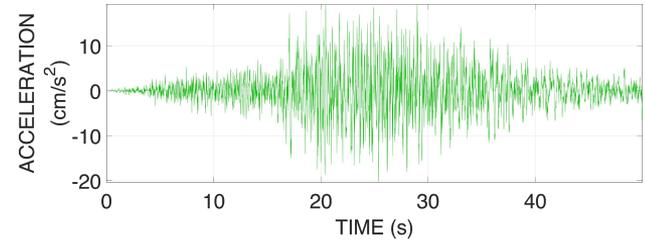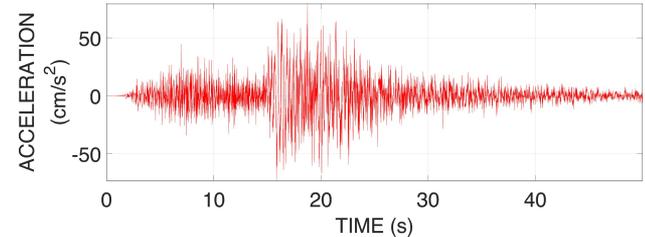
Time-frequency analysis of intrinsic mode functions decomposed from earthquake strong-motion data
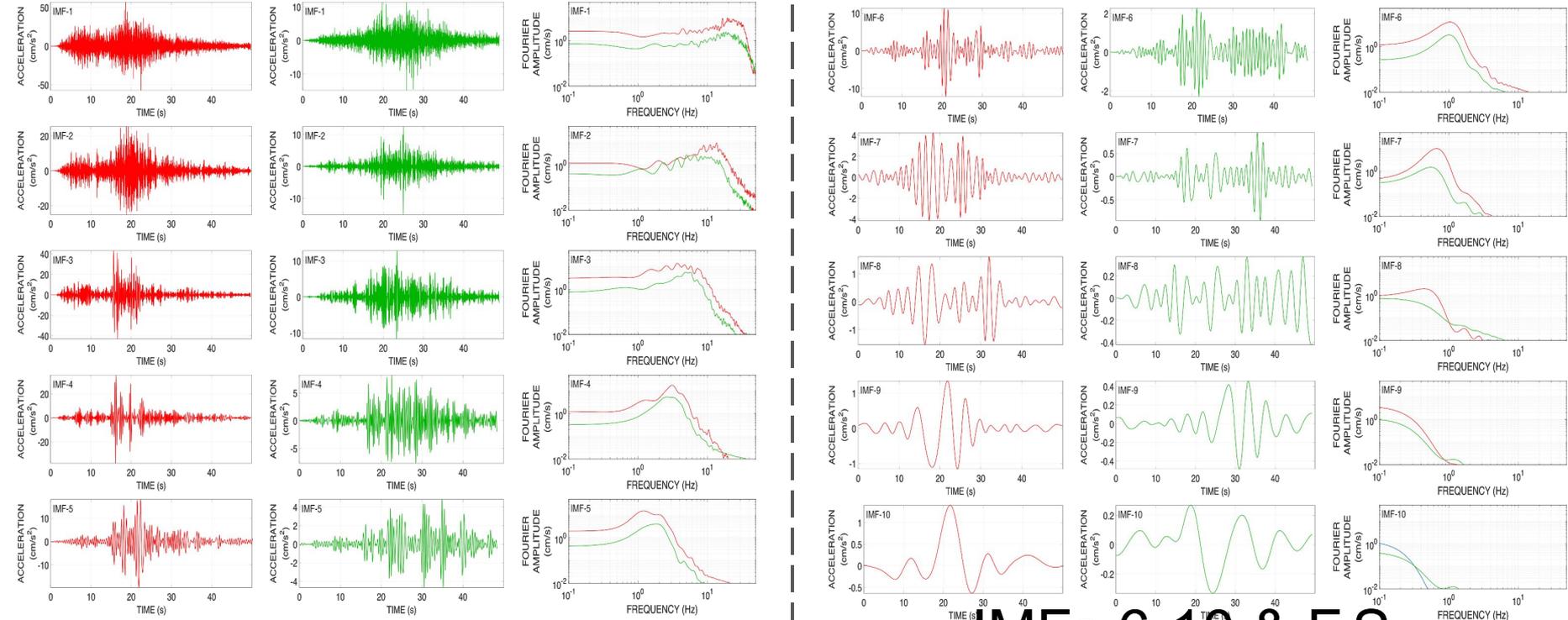
IMFs 1-5 & Fourier Spectra

IMFs 6-10 & F.S.

Studies show source signal contained in combination of IMFs

IMF 2   IMF 3   IMF 4   IMF 5
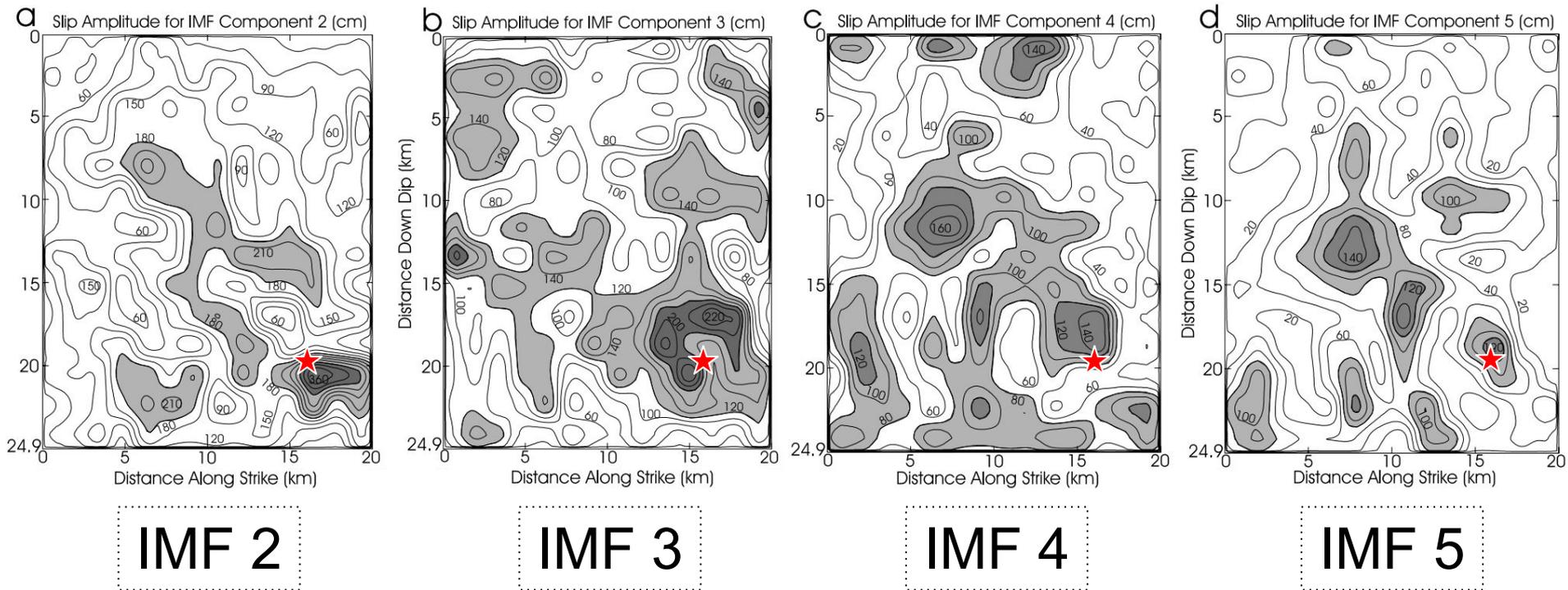
Progression of slip away from hypocenter from IMF 2 to 5

Zhang, Ma, and Hartzell (2003). BSSA, 93 (1): 501–518

High correlation between original signal and IMFs that best capture the original signal—possibly represent the source.

9
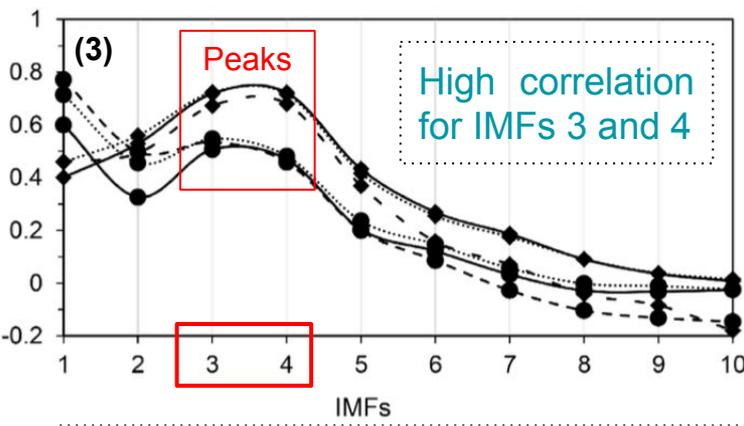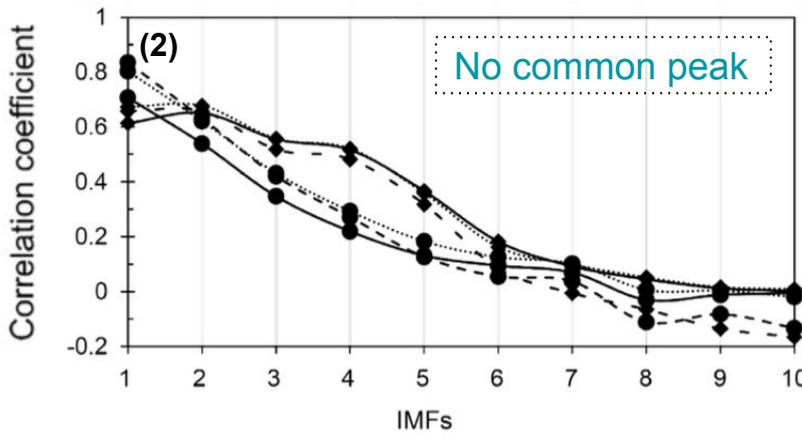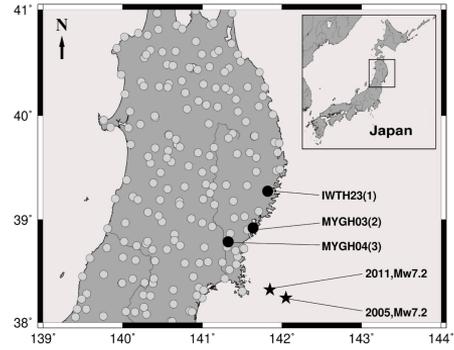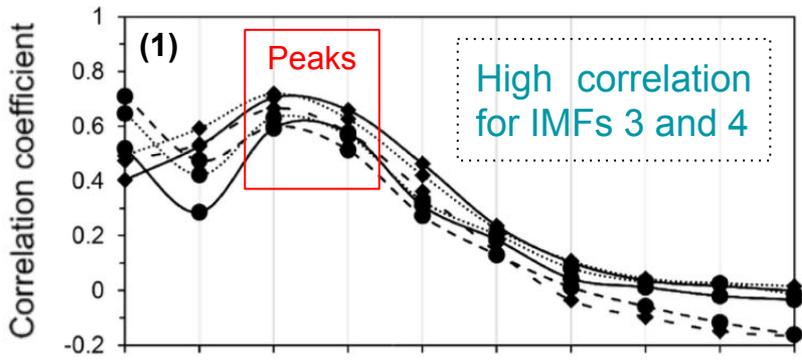
Linear combination of well-correlated IMFs gives a possible time-frequency representation of energy release.
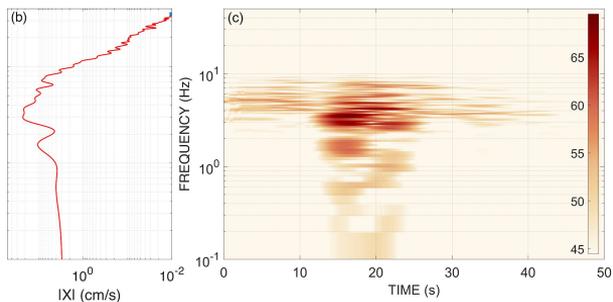

Spectrograms
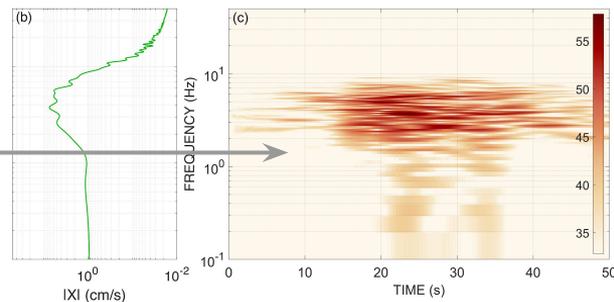
IMF 3 + 4
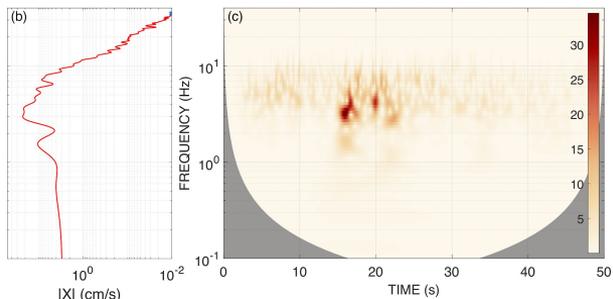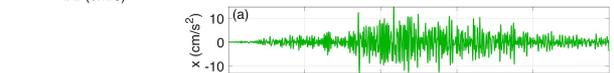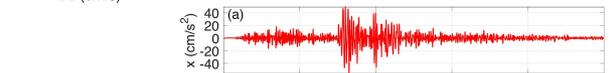
Scalograms

Intraslab

Interplate

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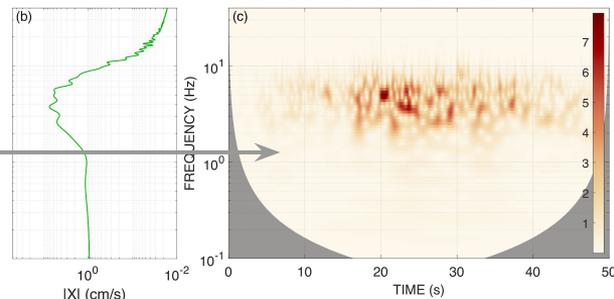
Joint study of teleseismic and strong-motion data connecting the energy release obtained from both
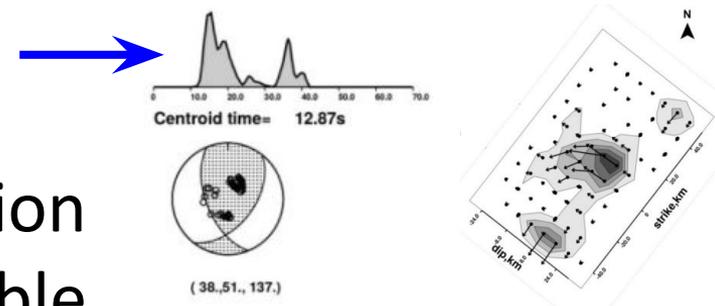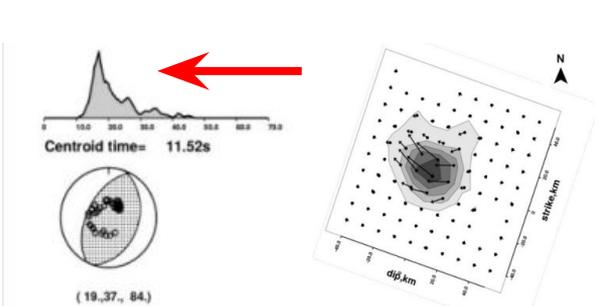
Shape and duration of MRF comparable with high-energy pulses & multiple patches in spectrograms

Intraslab

Intraplate

Chatterjee et al. (2018). AGUFM 2018, S33E-0636

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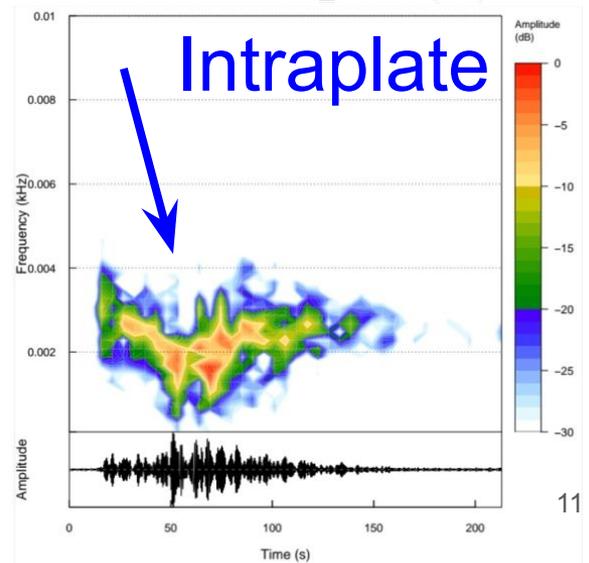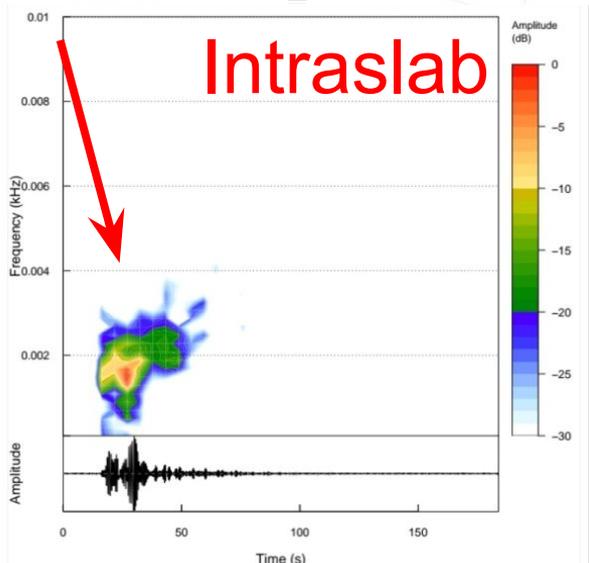
Improved resolution using the Hilbert-Huang Transform (HHT) = EMD + Hilbert Spectral Analysis

Hilbert transform, $\quad \hat{c}_k(t) = \dfrac{1}{\pi} \displaystyle\int_{-\infty}^{+\infty} \dfrac{c_k(\tau)}{(t-\tau)}\, d\tau$

Convolution with 1/t.
Focus on local properties of signal

Analytic signal, $\quad c_k(t) + j\hat{c}_k(t) = a_k(t)e^{j\theta_k(t)}$

Amplitude $a_k(t)$ and frequency of each IMF as a *f*(time)

Instantaneous frequency, $\quad \omega_k(t) = \dfrac{d\theta_k(t)}{dt}$

Local measure of frequency

Hilbert energy spectrum : **Amplitude^2 [$a_k^2(t)$]** values on time-frequency plane

Huang et al. (1998). Proc. Roy. Soc. London Ser. A, 454(1971), 903–995

HHT gives better resolution over spectrogram & scalogram

IMF 4

Spectrogram (STFT)   Scalogram (CWT)   Hilbert Spectrum (HHT)
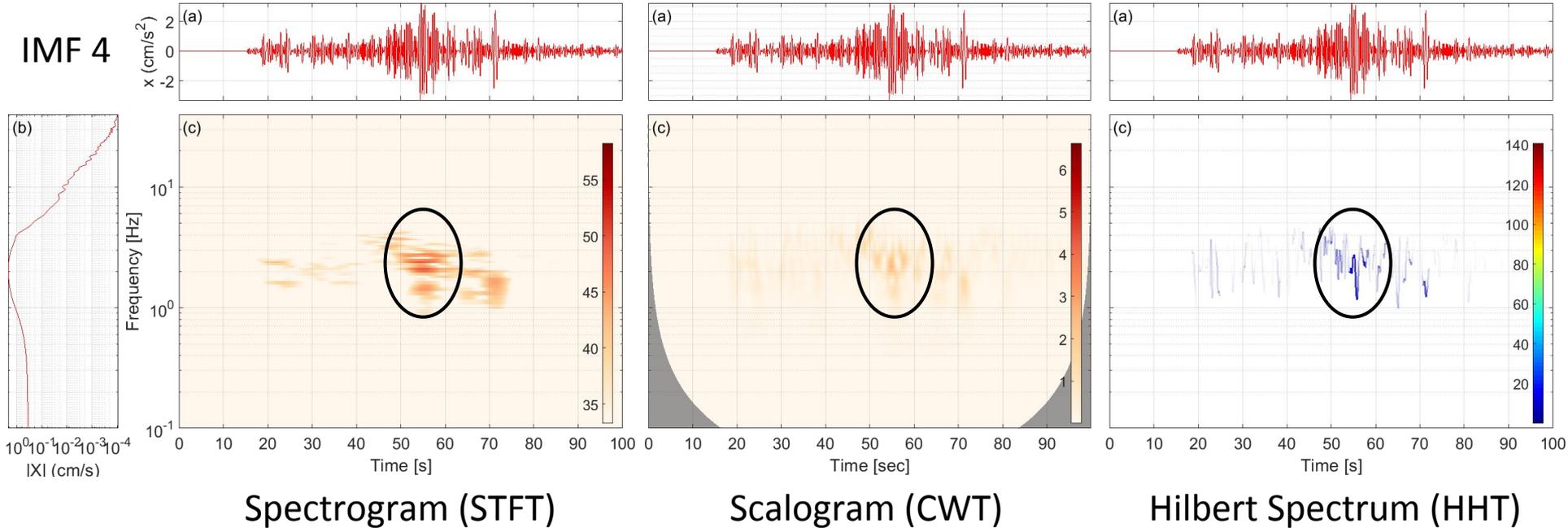
Improving resolution

Proposing station and IMF-selection criteria and expanding the analysis

2008/07/23 | Mw 6.8 (2)
IWTH02 (3.7)
AKTH16 (1)
IWTH04 (5)
IWTH26 (2.4)
2005/08/16 | Mw 7.2 (4)
2003/05/26 | Mw 7 (1)
YMTH02 (6)
2012/12/07 | Mw 7.2 (7)
2011/04/07 | Mw 7.1 (3)
2005/12/02 | Mw 6.5 (5)
2008/07/19 | Mw 6.9 (6)

Intraslab
Interplate
Intraplate

- Strong motion data (KiK-net, NIED, Japan)
- Borehole sensors (> 100 m)
- Vertical component

DISTANCE (km)

Trench axis

A   0
B   B'
Moho
Subducting Pacific Slab
W   E

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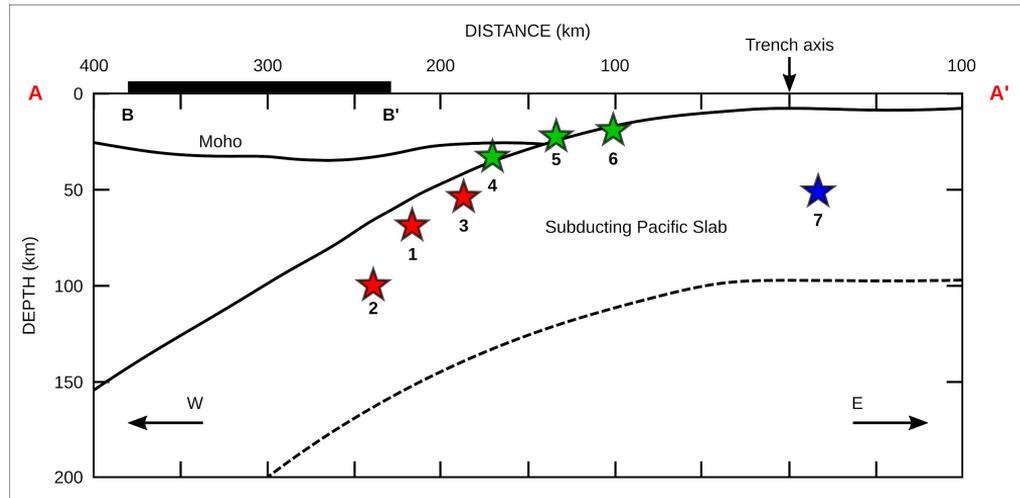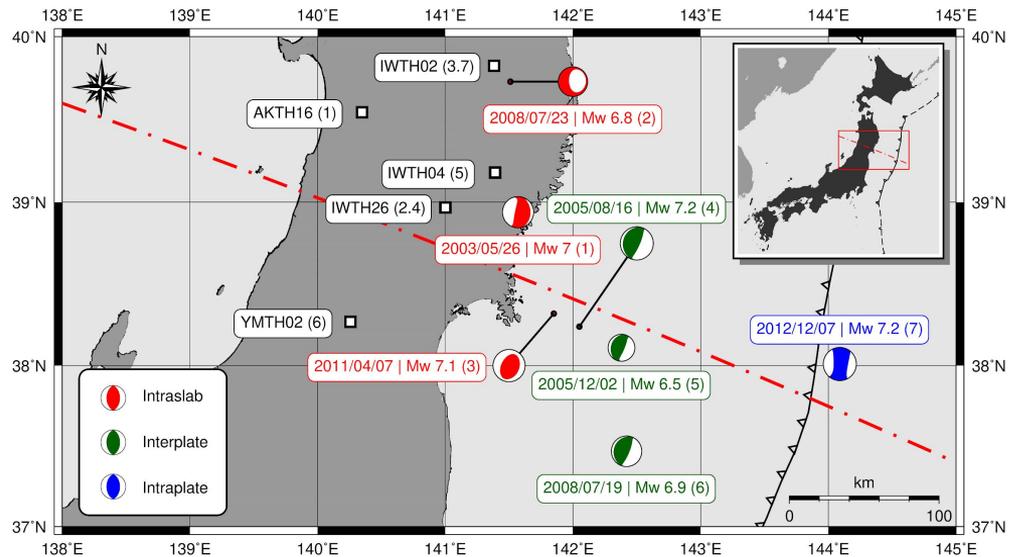
"Best" stations?
In the direction of rupture propagation and orthogonal to it.
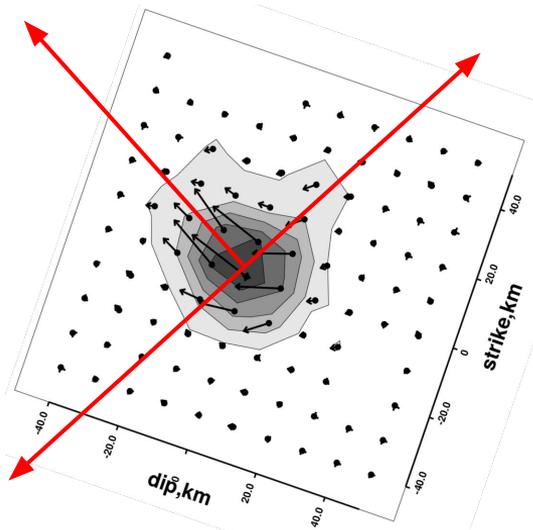
07 April 2011 Miyagi, M_w 7.1
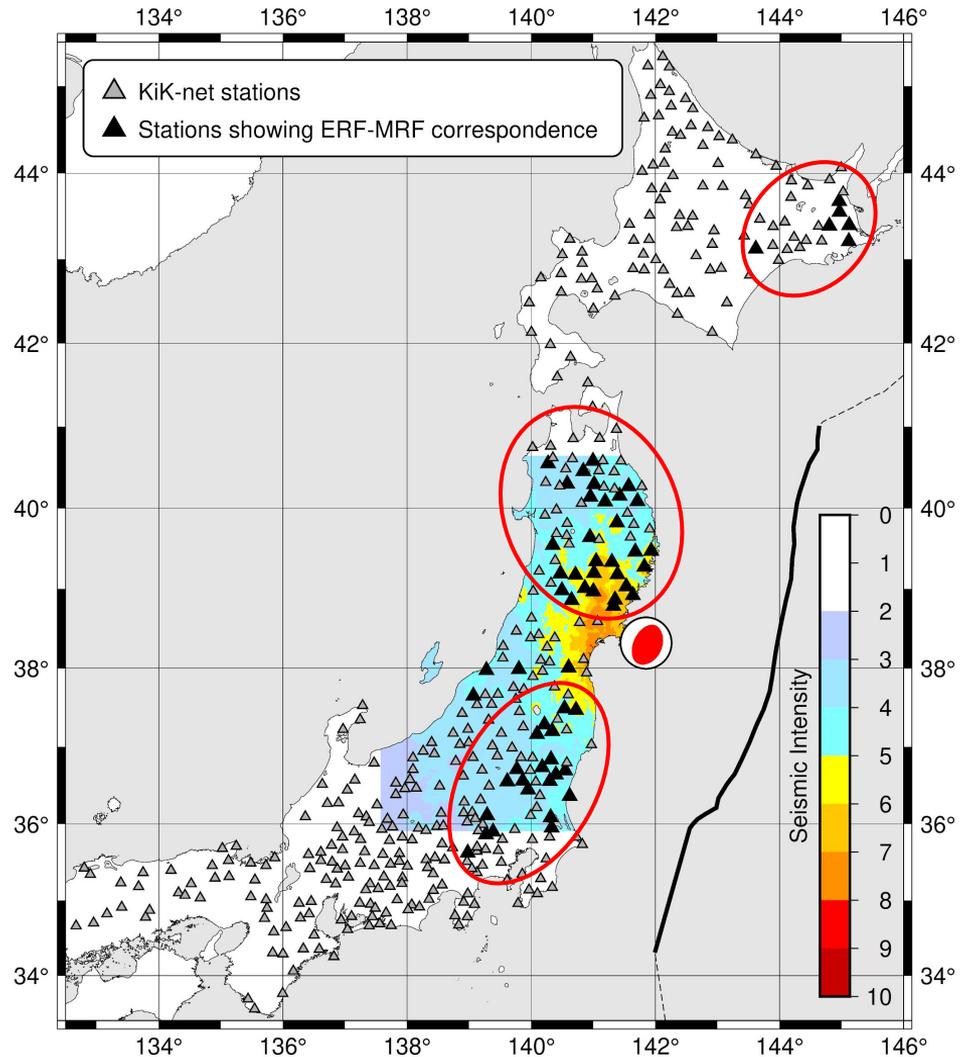
"Best" IMFs? Based on the frequency band, not the IMF number.
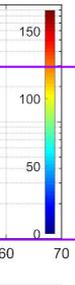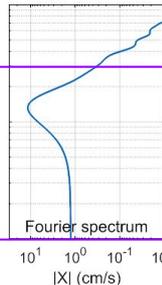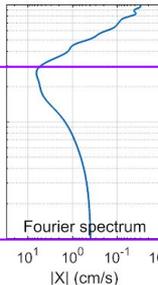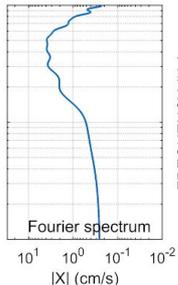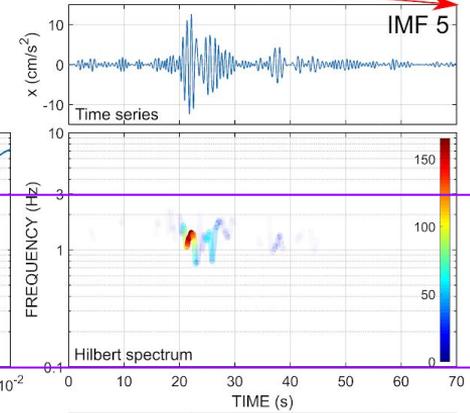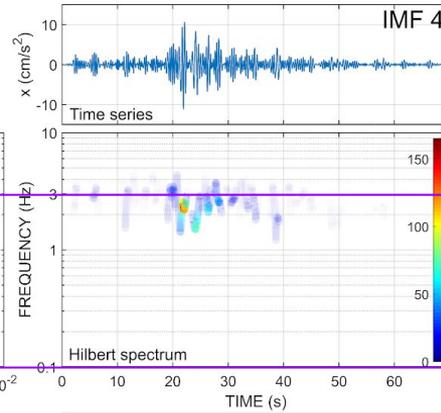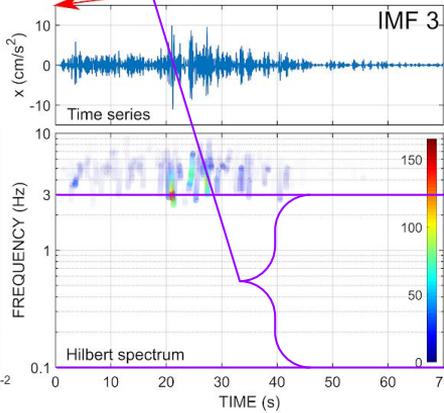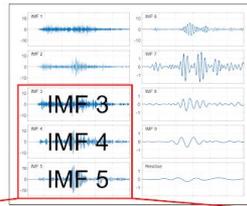
Generating an 'Energy Rate Function' by picking maximum energy values in the Hilbert spectra of the selected IMFs.
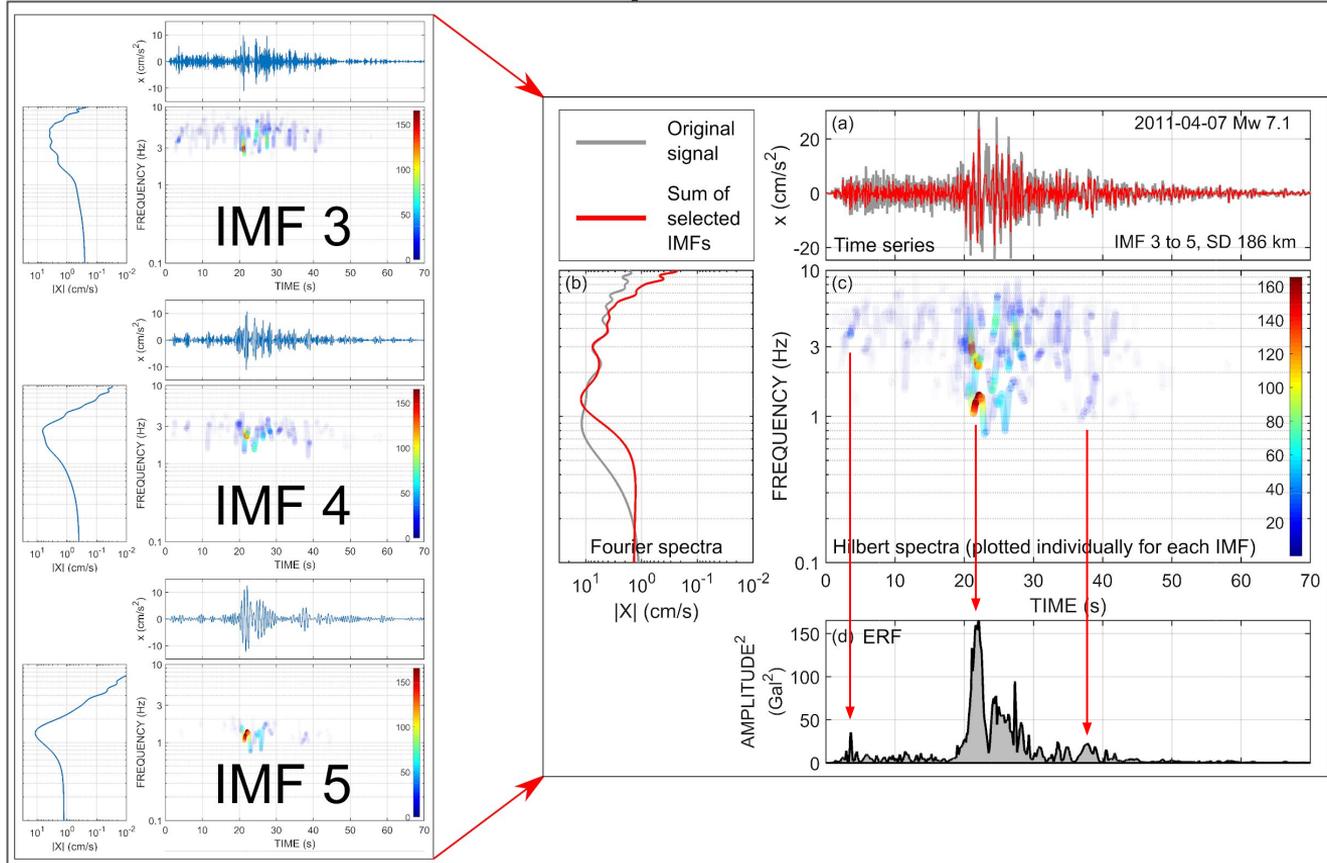
# Correspondence of the ERF with the MRF, with a few caveats (Time-frequency analysis vs. Waveform inversion)
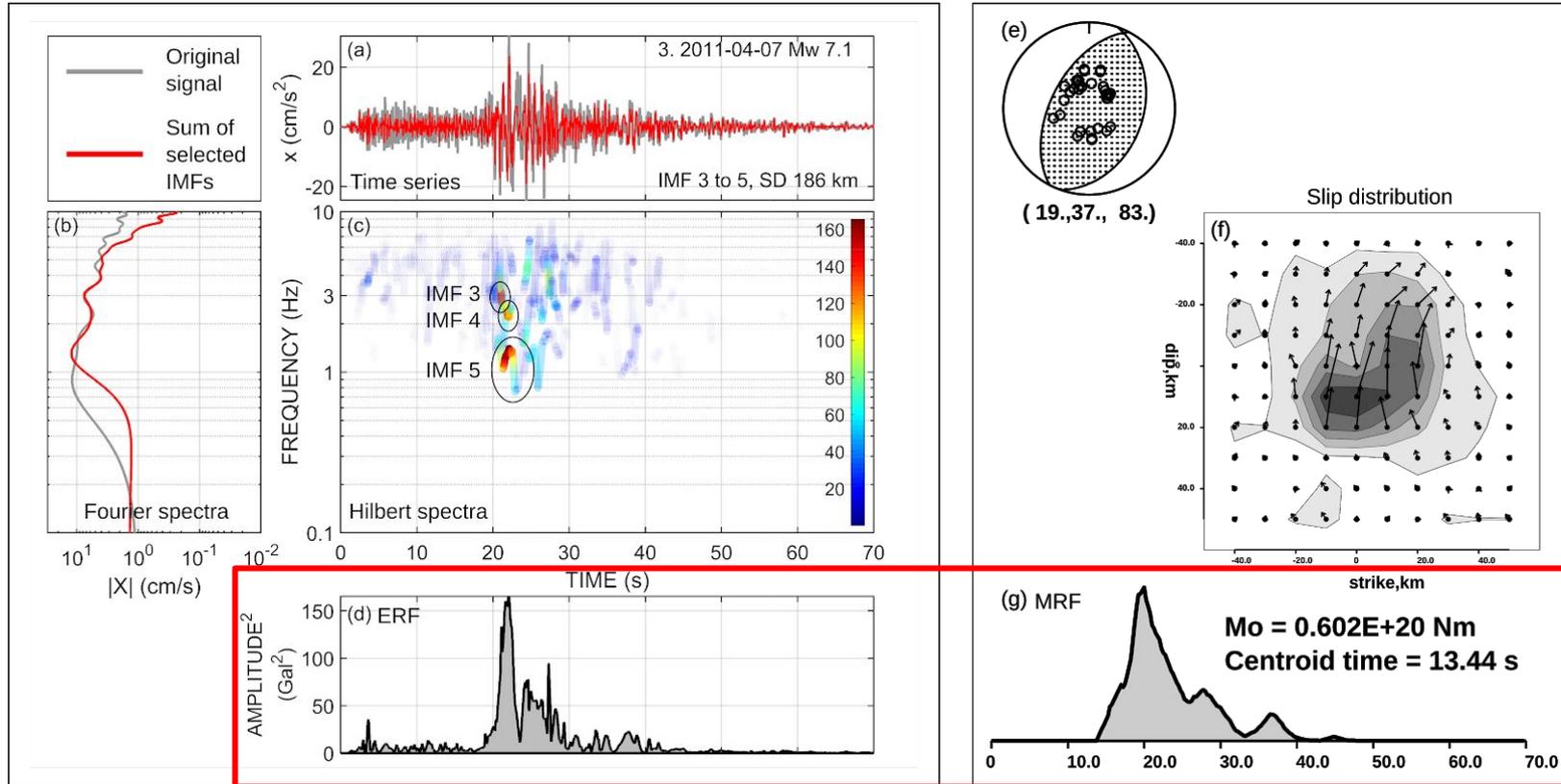
ERF-MRF correspondence observed at "best" stations (In the direction of rupture propagation and orthogonal to it).

ERFs

MRF
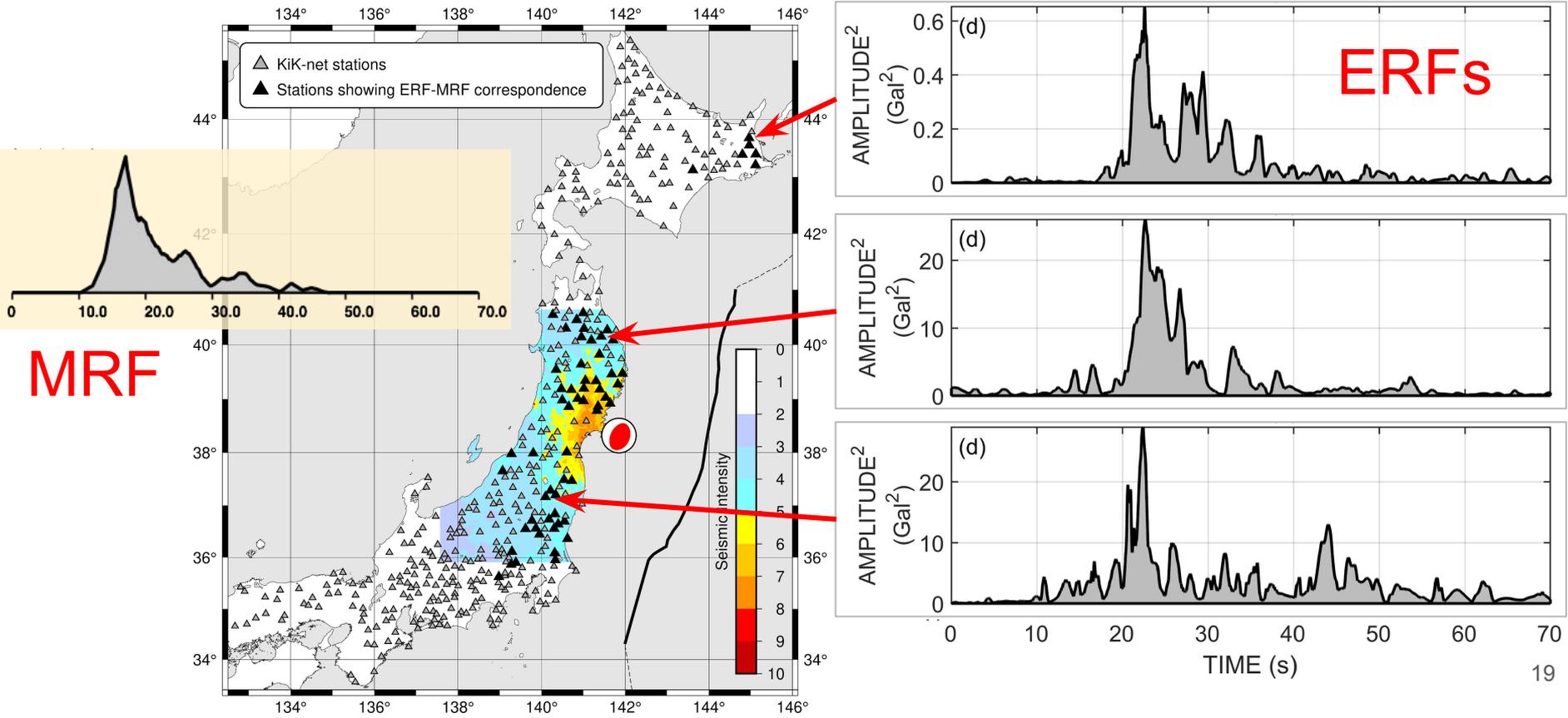
ERF-MRF correspondence for other tectonic settings

ERF-MRF correspondence for other tectonic settings

Interplate (2005 Miyagi-Oki): Complex rupture; rough ERF & MRFs.

Yaginuma et al. (2006). Earth, planets and space, *58*(12), 1549-1554.

Mo= 0.9 x 10^{20} Nm
Depth 36 km

Lay et al. (2012). *JGR: Solid Earth*, *117*(B4).

ERF-MRF correspondence for other tectonic settings
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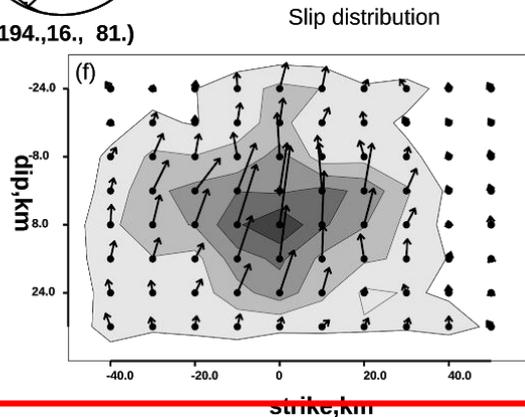
ERF-MRF correspondence for other tectonic settings
Interplate (2005 Honshu): Low seismic intensity stations; one IMF.

# ERF-MRF correspondence for other tectonic settings
## Intraplate (2012 Kamaishi): Complex rupture; 2 independent events
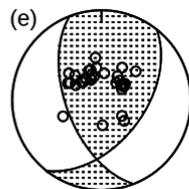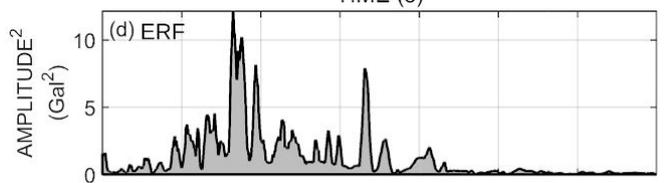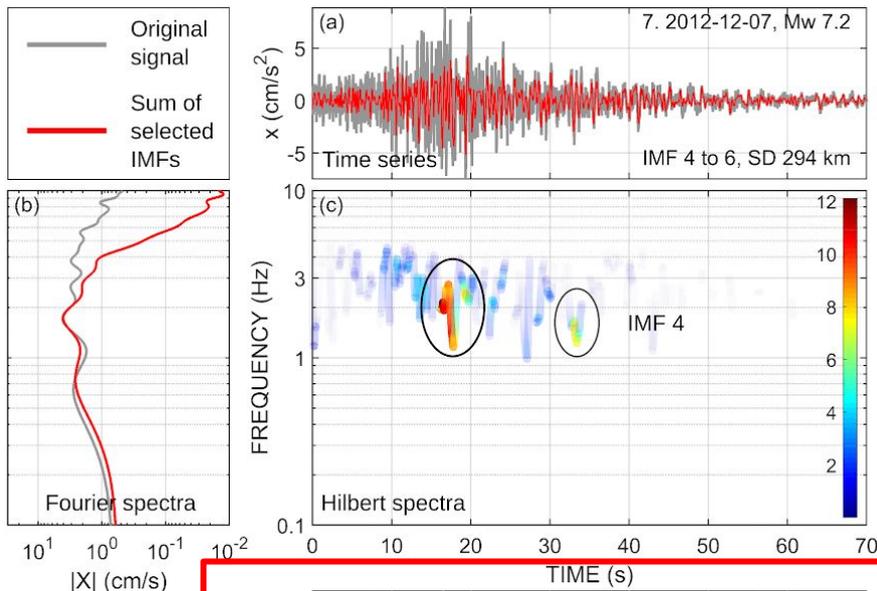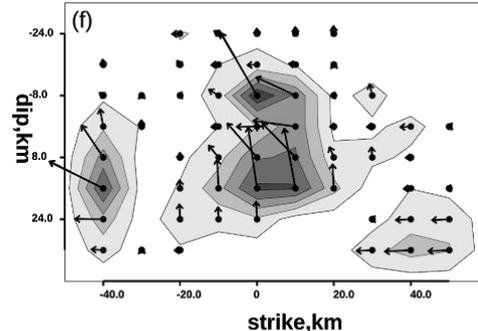
ERF-MRF correspondence for other tectonic settings
Intraplate (2012 Kamaishi): Complex rupture; 2 independent events
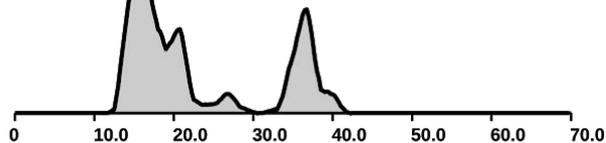
min.-misfit solution

double thrust source
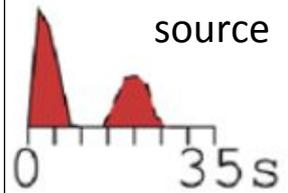
single-source inversion
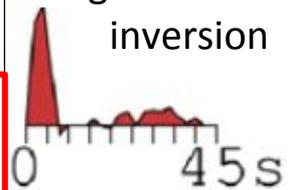
Craig, T. J., Copley, A., & Jackson, J. (2014). *GJI*, *197*(1), 63-89.

In conclusion, the combination of EMD with TFA tools is useful for quick interpretation of earthquake energy release.
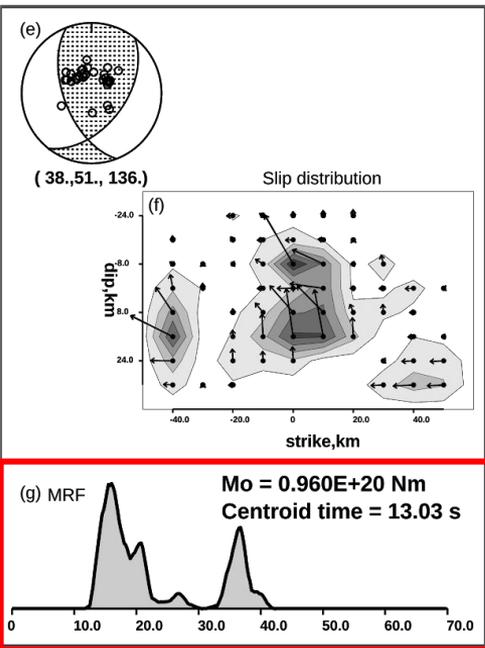
Waveform inversion
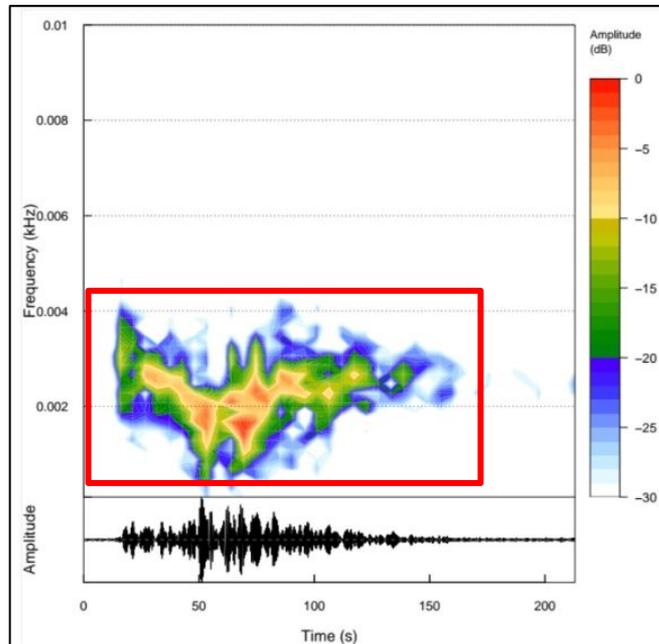
Spectrogram (strong-motion)

HHT-ERF (strong-motion)